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Patents ADP number *(if you know it)*	41907 40003	
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Wynne-Jones, Laine & James

12. Name and daytime telephone number of person to contact in the United Kingdom — W J NEWELL - 01242 515807

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Optical Devices

The present invention is related to an optical device, and a method for fabricating such a device, to articles incorporating such devices, and methods of authenticating articles, documents etc. using such devices.

In particular, but not exclusively, the invention relates to optical devices primarily used to provide optical security for valuable documents and identification products such as ID cards, passports, visas, currency and on branded goods. However such devices may be used more generally for other types of optical purposes.

There are, broadly speaking, a number of families of known optical security devices. One important type of these is known under the acronym DOVID (Diffractive Optically Variable Image Device), otherwise referred to herein as type A devices. In these devices images and/or information are encoded in the form of diffractive micro-optical structures. A large variety of different features based on diffractive structures is known. These include classical holograms but increasingly many of them use a variety of grating structures which allows for much wider range of visual impressions. Most DOVIDs in use today are manufactured as embossed surface relief microstructures by a process of roll to roll embossing into suitable thermoplastics, or by hardening of UV curable materials in contact with a master with a suitable relief structure. There are many different embossed substrates and several types of embossing systems in use depending on specific applications and volume of manufacture. These encoded diffractive structures usually produce a variety of image and colour effects which are visible to the

naked eye. In some cases machine readable diffractive features are also encoded for added security.

Prior to embossing, optical means or electron beam writing are used for origination. The output of the origination process, normally a surface relief hologram or diffractive structure formed in a photoresist type material, is converted and replicated into thin nickel embossing shims used for embossing. This is done by depositing a thin conductive layer on the resist master, using a silver spray or vacuum deposition system, before electroplating from this master a first thick metal copy master shim. A family tree of master and sub-master shims are then built up by successive electroplating process until the embossing shims themselves are produced. The typical pitch of the embossed structures is around 0.5 to 2.0 microns and depth around 0.2 to 0.5 microns. Other types of diffractive structures may be smaller or larger. The diffractive effects are mainly due to local orientations and spacings of grating structures, whereas the profile depths, to a first approximation, determine only the diffractive efficiency.

Embossing is normally done by attaching a shim around a heated roller and then embossing into a suitable thermoplastic substrate under heat and pressure. Other methods include hardening of UV curable materials in contact with the relief structure of the shim. To provide a reflective layer behind the embossed relief structure the materials are usually metallised with aluminium or other material using large roll vacuum coaters, although other reflective layers are possible to give different results. After metallisation the materials are adhesive coated. Various adhesive materials are normally used, carefully tailored for each application, paper and application process. Following these

steps the materials are slit, die cut in the case of labels and then, if required, individually numbered using, for example, inkjet or thermal printing systems for applications requiring audit control or traceability.

Examples of origination, mastering and manufacturing are well known, for example in the following publications and references therein:

"Developments and applications of diffractive Optical Security Devices for bank notes and high value documents", Proceedings of SPIE, Vol 3973 (2000), pp 65-77;

"Non-standard Diffraction Structures for OVDs", SPIE Proc, Vol 3314 (1998), p 194

"Optical Document Security", Rudolf van Renesse, editor, Artech House 1994 (IBSN: 0-89006-619-1)

"Practical Holography", Graham Saxby Prentice Hall 1988 (ISBN 0-13-693797-7, Chapter 20 – Embossed Holograms)

In a second family of optical security devices (referred to herein as type B devices) image/information are encoded as structured optical retarders (normally latent in unpolarized light). Generally the image is invisible when viewed by the naked eye, but becomes visible when viewed with the aid of polarizers. U.S. Patents 5,284,264 and 6,124,970 disclose simple methods of creating and viewing such images. Another method of creating and viewing these elements are disclosed in the references listed below. This method uses a linear photo-polymerisable process (LPP) for photo-patterning of liquid crystal aligning layers to produce spatially patterned optical retarders when a suitable layer of liquid crystal monomers or polymers is coated on top of the LPP layer. The orientation

of nematic liquid crystal molecules is defined by the nematic director. The orientation layer consists of a photo-oriented polymer network (LPP) which defines regions of alternating orientations in an adjacent liquid crystal film. The orientation is characterized by a spatially-dependent variation of the direction of the optical axis which is fixed by a subsequent cross-linking step, after which a cross-linked, optically structured liquid crystal monomer or pre-polymer (LCP) with a pre-established orientation pattern is formed.

The LPP layer is coated with a thin film of cross-linkable liquid crystal monomer or a pre-polymer mixture which exhibits birefringence that corresponds to a required retardation (λ/2, λ/4 etc). The LCP layer therefore generates the optical retarder effect. By combining LPP/LCP films with specific retardation values colour effects can be produced. The origination, mastering and manufacturing processes of this class of type B device are completely different from those used for type A devices. In general, they are less suitable for volume low cost manufacturing as they require direct exposure of each element produced.

A description of this method can be found and the following publications and references therein:

US 5,284,264

US 6,124,970 (WO 0,992,1035)

"Optical LPP/LCP Devices – A new Generation of optical security elements" Proceedings of SPIE Vol 3793 (2000), pp 196-203.

"New coloured Optical Security Elements using LPP/LCP Technology" Proceedings of SPIE Vol. 4672 (2002)

EP 0,689,065

EP 0,689,084

US 6,496,287

In a third family of optical security devices, liquid crystal effects and diffractive effects are combined but there is no optical synergy or interaction between the two effects; these hybrid devices are referred to herein as type C devices. In a development by NHK Spring (Japan) diffractive and interference effects are used to form the so called CPLgram (CPL stands for Circularly Polarized Light). A semi transparent thin film of polymerised Cholesteric Liquid Crystal evokes the interference effect, while embossed diffraction gratings are underneath this LC film. In specular reflection, the LC film act as an efficient Bragg mirror and reflects a waveband that shifts from gold to blue-green with angle of observation. Both this Bragg reflection and the light diffracted from the embossed features are circularly polarized. In this device the gratings and the Cholesteric Liquid Crystal structures are separate. The Cholesteric LC layer is just overlaid, the grating does not align the LC and the LC does not comply with the grating structures.

Reference is directed to the following references:

US Patent 6,301,047 B1

EP 0911758 A3

EP 1327895 A1

WO 03/069587 A1

SPIE Proc, Vol 3793 (2000), p133

SPIE Proc, Vol 3793 (2000), 238

There are a number of ways of aligning liquid crystal materials on surfaces. One method, as mentioned above, is using a photo oriented polymer network (LPP).

Another proposed method of aligning liquid crystal materials is by micro-grooved or micro-structured surfaces. Some of these liquid crystal materials can also be polymerised to create fixed structures, which exhibit optical retarder effects as in type B devices. E.S. Lee et al listed below describe structures of microgrooves of 0.05 micron and .525 micron pitch and of .278 micron and 1.11 micron depth respectively. Sovoliev et al, listed below, describe grating structures of pitch between 2 to 5 micron and depths of 0.08 to .4 micron.

Information can be found in the following:

"Alignment of liquid crystals by grooved surfaces", Dwight W Berreman, Molecular Crystals and Liquid Crystals, Vol. 23 (1973), pp 215-231.

"Control of liquid crystals alignment using stamped morphology", E.S. Lee et al, Japanese J of Applied Physics, Vol. 32 (1993), pp L 1436 – L 1438.

"Alignment of reactive LC mesogen by relief diffractive grating", Vladimir Sovoliev et al, Proceedings of SPIE Vol. 4658 (2002), pp 133-136.

WO 03/062872

"Photopolymerisation of reactive Liquid Crystals", D.J. Broer SID 95 Digest, pp 165-169

"Merck Technical Sheet, Coatable Solutions of Polymerisable Nematic Mixture".

Summary of the Invention

According to one aspect of this invention there is provided an optical device comprising a first layer having a micro-relief pattern over at least part of said first layer designed to produce a pre-determined diffracted first image when appropriately illuminated in use, and an optically anisotropic second layer provided on said first layer wherein at least part of said micro-relief pattern induces local orientation of said optically anisotropic second layer thereby to impose a pre-determined polarization modulation, thereby to produce a pre-determined second image when appropriately illuminated and viewed in use.

In this aspect, the device is essentially a single device which uses the same structured layer to encode both diffractive (type A) and optical phase (type B) features. The pattern on the structured layer is typically in the form of a micro-relief pattern which acts also as an alignment surface to align the optically anisotropic second layer to provide a phase-modulating structure. In this way, the device displays the optical security features of the type A devices as well as optical phase features of the type B devices.

It should be appreciated that the term 'image' is used broadly to cover any optically discernible pattern which in its simplest form may comprise a pattern of light and dark regions. Although in many instances, the optical device may be designed to be viewed and authenticated in the visible band of radiation, it will be appreciated that the light used to illuminate the device may be outside the visible range. The 'image' may be viewable by the naked eye or with the aid of a simple optical device or by a suitable machine.

The optically anisotropic second layer may be of any suitable material

that modulates the polarization mode of radiation incident thereon, such as e.g. a suitable liquid crystal material which is capable of being processed to form a solid film so that the molecular alignment between the film and the aligning layer can be suitably preserved. These materials include, for example, polymerisable liquid crystalline materials and polymer liquid crystal materials.

In this manner, the same origination and manufacturing process may be used to provide both types of security features. These devices can be mass produced by using origination, mastering and manufacturing techniques similar to those produced for type A. Hence type B effects and combined type A and type B effects could be integrated with a type A effects, on a single conventional type A device. In this way security is enhanced with little or no added origination, mastering and manufacturing costs.

The first layer of the device may include one or more relatively strongly diffractive micro-relief regions having a significant diffractive effect and one or more relatively weakly diffractive micro-relief regions where there is little or no diffractive effect. In the regions where there is little or no diffractive effect, the first layer may still include a micro-relief structure capable of orienting the optically anisotropic second layer.

Preferably the first layer includes a plurality of areas or domains, each of which having a respective orientation of the micro-relief pattern thereon, defining respective optical axes.

In one arrangement, the pitch and the structure depth of the micro-relief patterns may be generally similar to those used in conventional type A devices so that the finished device provides both a significant diffractive effect and also

phase modulation properties. For the visible wavelengths, typical values for pitch for the structure lie in the range of 0.5 µm to 2.0 µm and for depth 0.2 to 0.5 µm .

However, where there are instances where it is required for there to be little or no diffraction, the appropriate area or domain of the first layer may have a micro-relief pattern depth of less than 0.05 µm. This will produce very poor diffraction efficiency. Furthermore, if a pitch of less than 0.2 µm is selected then all diffraction orders in the visible region will be suppressed.

The devices of this invention may be used either in transmission or reflection mode.

In one embodiment, the coating thickness of the optically anisotropic second layer is selected having regard to the frequency of the intended illumination in use to provide a ½ λ phase retardation when appropriately viewed. In another embodiment, the coating thickness may be selected to provide a ¼ λ phase retardation when appropriately viewed.

It will be appreciated that this allows optical devices to be produced with various adjacent domains. Each domain may provide both a diffractive effect and a phase modulation or retardation effect, or it may provide just a phase modulation or retardation effect only. In the latter instance the local micro-relief structure will be such as to provide little or no diffractive effect. In other instances, depending on the polarization of the illumination light, it may be possible to provide domains in which the polarization modulation effect, whilst present, is not apparent, due to the appropriate orientation of the plane of polarization of the illumination light with the optical axis of the anisotropic second layer.

In order to provide further modulation effects, the thickness of the coating of the optically anisotropic layer or its birefringence may vary with position across the device, to vary the optical retardation induced thereby. In one example, the first layer is provided on a stepped substrate, whereby adjacent micro-relief patterns are stepped in the vertical sense (that is in the sense of the thickness of the layer) by a step distance which is substantially greater than the micro-structure pitch dimension, thereby to provide regions of respective selected retardations.

In another arrangement, the first layer may be generally continuously contoured and so, for example, the first layer may be generally planar but non-parallel to the upper surface of the optically anisotropic second layer.

As noted, the optical device may be used in reflection or transmission modes; when used in reflection mode, the interface between the first layer and the optically anisotropic second layer may be rendered reflective over at least part thereof. Alternatively, the first layer may be provided on a transmissive substrate and at least part of the surface of the substrate remote from the interface with the optically anisotropic second layer may be reflective. Thus in some arrangements, the reflective surface may be provided over only part of the device, such that it is used partly in reflection mode and partly in the transmission mode.

By providing e.g. stepped variations in the coating thickness of the optically anisotropic layer, specific retardations may be provided which may provide a colour effect in response to illumination with visible radiation when appropriately viewed.

The invention also extends to a method of producing an optical device which comprises providing a first layer having a micro-relief pattern over at least part of said first layer designed to produce a pre-determined diffracted first image when appropriately illuminated in use, and applying to said first layer a coating of an optically anisotropic second layer, wherein at least part of said micro-relief pattern induces local orientation of said optically anisotropic second layer thereby to impose a pre-determined polarization modulation and thereby to produce a pre-determined second image when appropriately illuminated in use.

The micro-relief pattern may be produced in a variety of ways including embossing.

The invention extends to an article including an optical device as described above.

The invention further extends to a method of authenticating an article which comprises of applying to said article an optical device as described above to provide identifiable first and second images when appropriately viewed, and thereafter examining said article for presence of said first and second images.

It will be appreciated that the reading of the first and second images may be by the naked eye or by machine and in certain circumstances, one image may be read by eye and the other by machine, or by the naked eye with the aid of a simple optical element.

Whilst the invention has been described above, it extends to any inventive combination of the features set out above or in the following description.

Description of the preferred embodiments

The invention may be performed in various ways, and various embodiments thereof will now be described by way of example only, reference being made to the accompanying drawings, in which:-

Figure 1 is a schematic view of a typical known form of embossed holographic or diffractive security device (type 'A') for use in reflective mode;

Figure 2 is a schematic view of an alternative version of a type 'A' device;

Figure 3 is a schematic view of a type 'A' device when used in transmissive mode;

Figure 4 is a schematic view of an optical device in accordance with an embodiment of the invention, for use in reflective mode;

Figure 5 is a schematic plan view of an optical device in accordance with this invention showing an arrangement in which the relief pattern is arranged in regions or domains of different orientations;

Figure 6 is a view of an optical device in accordance with this invention for operating in transmissive mode;

Figure 7 is a plan view of a embodiment of this invention including various domains, some of which apply type 'A' and type 'B' effects, and some of which apply type 'B' only, and

Figure 8 is a schematic view of a further embodiment of this invention comprising a stepped substrate layer on which a relief structure is provided to provide an anisotropic layer of stepped thicknesses.

Background

It has been shown that surface relief structures of diffractive elements (or

indeed various different surface relief patterns or functions) can be made into suitable receptive material by any one of many known methods.

Figure 1 of the drawings shows the basic structure of embossed holographic or diffractive security device, referred to above as a type 'A' device. As shown, the device comprises a substrate layer 10 of a UV curable resin or an embossable thermoplastic. The substrate carries a micro-relief grating pattern 12 and a very thin layer of metal or multi-layer reflective coating 14 (eg vacuum deposited). An upper layer 14 of UV curable resin or other isotropic material with a refractive index n of typically around 1.45 to 1.6 is coated onto the substrate. In such an arrangement, with an embossed surface with pitch p, the direction of the diffracted orders is determined by:-

$$\mathrm{Sin}\,(\theta_m) = \mathrm{Sin}\,(\theta_o) + m.\lambda/p \text{ (Equation (1))}$$

Where λ is the wavelength of the diffracted light, p is the grating pitch (period) and m is the diffraction order. θ_m and θ_o correspond to the angles between the normal to the reflection surface and the directions of orders m and 0. when m = 0, (zero order), this corresponds to the mirror reflection (undiffracted light).

In practical devices used in security applications (holograms, diffractive gratings) typical parameters are:

D (structure depth) about 0.2 to 0.5 μm

p (structure pitch/period) about 0.5 to 2.0 μm

In Fig.(1) for the first order $\sin(\alpha) = \lambda/p$, where α is the angle between the light diffracted into the first order and the mirror reflection (zero order).

For λ = 0.5 μm (average of visible light), and p = 1 μm, the above

expression gives $\alpha = 30°$.

It should be noted that for the special case of vertical illumination the values $\theta_0 = 0$, $\theta_m = \alpha$ are obtained.

The diffractive effects are mainly due to the local orientations and spacings of the gratings. However, the profile-depths of the grating, to a first order, determine the diffraction efficiency.

Referring to Figure 2, in another type of reflective mode device, instead of providing a reflective layer 14 between the substrate 10 and the upper layer 16, the surface of the substrate remote from the interface may be made reflective, as shown by reflective layer 18 in Figure 2.

The devices can be made to work in transmission. Referring to Figure 3 in transmissive mode both the upper layer 16 and the substrate 10 are transparent. To have sufficient diffractive efficiency, the refractive indices of substrate 10 (n_1) and layer 16 (n_2) must differ in order to avoid index matching. Practical curable resins can give:

$$\Delta n = n_1 - n_2 = 0.2$$

$$n_1 \sim 1.4$$

$$n_2 \sim 1.6$$

Therefore the depth of the structures should in general be larger than in the reflective case to get sufficient difference in the optical path. The other parameters and structures are similar to the reflective case.

The operation of type B devices which use liquid crystalline materials to provide optical phase modulation/retardation are described in e.g. "Optical LPP/LCP Devices – A new Generation of optical security elements" Proceedings

of SPIE Vol 3793 (2000), pp 196-203 and "New coloured Optical Security Elements using LPP/LCP Technology" Proceedings of SPIE Vol. 4672 (2002). The operation of a transmissive and reflective device is also explained in these references.

First Embodiment

Referring to Figure 4, in this embodiment, the whole area of the device acts both to apply a diffractive effect (type A) and a phase modulation/retardation (type B).

In this case the relief structure (p, D) is similar to that described in that of the previously described grating design for a Type A diffractive security optical device.

In this embodiment the polymerisable liquid crystal material is selected to be that obtainable under the trade configuration RM34 (from Merck). This material has extraordinary and ordinary refractive indices $n_e = 1.68$ and $n_o = 1.525$, giving $\Delta n = 0.155$.

The optical retardation δ is given by $\delta = 2d\,(n_e - n_o)$, the factor 2 being because the device is used in reflective mode. d is the thickness of the optically anisotropic layer.

For $\lambda = 0.5$ µm for average visible light, this gives:

$d = 0.8065$ µm for (½ λ plate)

$d = 0.4032$ µm for (¼ λ plate)

It will be appreciated that a ½ λ retardation alters the direction of polarization of a linearly polarized light, and the angle of rotation depends on the angle between the direction of polarization and the optical axis of the optically

anisotropic second layer. A ¼ λ retardation converts linearly polarized light into circularly polarized light.

In this embodiment the whole device works both as a diffractive device (type A), and also as type B when viewed appropriately. In the case B the modulation of the polarization follows the orientation of the diffractive pattern.

In this embodiment, there is provided a substrate 20 similar to that of type A devices, made of suitable material e.g. UV curable resin or embossable thermoplastic resin. In this particular embodiment the device is used in reflective mode. The upper surface of the substrate carries a relief structure 22 and this has a reflective layer 24 as previously. On top of the substrate 20 is coated an optically anisotropic layer 26 such as a liquid crystal polymer or a polymerisable liquid crystal material. The thickness 'd' of the layer is chosen to give the required retardation as previously explained.

Thus when used as a security device authentication involves the steps of checking for a diffractive image (by the naked eye or by machine) and also for a related polarization modulation/phase retardation giving a second image when viewed through one or more appropriately aligned polarizers with defined polarization properties.

Referring to Figure 5, in this embodiment, the orientation of the patterns may be arranged in differently aligned domains or regions 28, 28', 28", 28'" etc. in each of which the pitch and depth of the relief structure lies within those of the visible diffraction regime, i.e. D = 0.2 to 0.5 μm and p = 0.5 to 2.0 μm. So as to give corresponding regions in which the optical axis is aligned at different orientations.

Note also that this embodiment may be modified by rendering the lower surface of the substrate reflective rather than the interface between the substrate and the liquid crystal material.

Second embodiment

In this embodiment illustrated in Figure 6, the device is constructed to be viewed in transmission mode. The substrate 20 is isotropic but transparent and carries a micro-relief diffractive structure 22 which serves also to align the anisotropic liquid crystal material layer 26.

In this case the retardation is given by $\delta = (n_e - n_o).d$, and so for ½ λ requires d = 1.613 μm (λ = 0.5 μm).

In a variation of embodiment, the interface may be only partly coated with a reflective layer, with the remainder being transmissive so that the device operates as ½λ plate in transmission and a full λ plate in reflection (e.g. no retardation). Accordingly, in this variation a thickness d = 0.8065 μm may be selected to give operation of ¼λ in transmissive mode and operation of ½ λ in reflective mode.

Third embodiment

In this embodiment, all or part of the optical device is constructed so that, although the substrate carries a micro-relief grating structure, its diffractive properties are minimal or negligible. Referring to equation (1) it will be seen that if p (pitch of the grating) is small (e.g. p = 0.2 or 0.1 μm or less) then all the diffractive orders are suppressed and the device in visible light operates as a zero order device. Furthermore, if the depth of the structure is very small, e.g. D ~ 0.05 μm or less, then it is known from diffraction theory that the diffraction

efficiency of the grating will be very poor, in fact very little light is diffracted. However with these parameters (e.g. p ~ 0.1 μm, D ~ .05 μm) it should be emphasised that alignment will continue to occur quite efficiently, and this regime may be termed "alignment only". In this regime the grating parameters for p or D are as above. In practice the device will diffract poorly if either of the parameters is in this regime and certainly does so if both are of the same regime.

This allows provision of selected domains which operate as in the first and second embodiments, e.g. acting as type A and B, and other selected domains which act only as type B (e.g. which do not diffract, but do alter polarization). A significant advantage is that both features can be placed on the same device using the same origination and manufacturing process. The other parameters regarding materials, thickness of coating etc. are the same as in the previous embodiments. The device may be suitably constructed to operate in transmissive and in reflective modes.

An example of such device is shown schematically in Figure 7. In this example the device has three distinct regions; the left hand and right hand regions 70, 72 respectively are standard diffractive regions and carry micro-relief structures which have pitch and depth dimensions to provide a visible diffractive image, and they also act to align the liquid crystal material to provide optical retardation/polarization modulation. They therefore function as type A and B regions. In this example, the thickness of the liquid crystal material over the whole device is selected to give ½λ retardation in reflective mode. The illustrated device is intended to be viewed for authentication purposes through a suitable

polarizer (not shown) with its plane of polarization at +45° to the edge of the device. In the left hand region there is a first domain 74 in which the micro-relief grating pattern is exactly aligned with the +45° orientation of the polarizer. Thus the optical axis of the liquid crystal material in domain 74 will be exactly aligned with the plane of polarization. In this region, when viewed in reflection mode via the polarizer, the liquid crystal material will not affect the polarization and so the image will look bright (and also will diffract). However in the other domains 76, 78 in the left hand region the optical axis is at +45° and -45° respectively to the plane of polarization and so when viewed the image will look dark because the polarization plane of the light in each case is rotated through 90° so that it is blocked. Likewise, in the right hand panel 72, domains 80 and 86 in which the micro-relief grating pattern extends ±45° to the plane of the polarizer will appear black, whereas domains 82 and 84 in which the pattern extends at 0° and 90° to the plane of the polarizer respectively, the region will appear bright.

It will be noted that the 90° pattern to the plane of the polarizer merely causes the polarization to be rotated through 180° and thus light will pass through the polarizing filter.

The central section 88 is a region of little or no diffraction e.g. with pitch and depth of 0.1 μm and 0.05 μm respectively. Different orientations can be designed to cause different (or no) modulation of linearly polarized light. The background is a pattern which aligns the optical axis of the liquid crystal material to +45°, whereas the letter A is a region in which the liquid crystal material is aligned to 0°. In this example the letter A will be invisible when viewed by the naked eye (because there is very little diffraction and so the whole surface will

appear as a reflector). However, when a polarizer aligned at +45° is used, the letter A will become visible. The background region does not alter the polarization of the reflected light because of alignment between its optical axis and the polarizer. The pattern in the letter A will rotate the +45° polarization plane by +90° and the letter A will appear black when seen through polarizer at +45°.

In this embodiment type A and B and type B only domains are provided side by side on the same device. Again, both the same substrate and the same origination and manufacturing processes as well as materials.

As explained above in connection with the domains 82 and 84, it is possible to have arrangement in which only diffraction will be visible and the polarization is not modified (e.g. type A only) even when viewed with polarized light through a polarizer. It will be appreciated that, as the micro-relief pattern is in the form of parallel straight lines, it effectively determines the direction of the optical axis, and so any linearly polarized light which is parallel or vertical to these gratings is unaltered.

Thus whether viewed with the naked eye or through a polarizer at 0° or 90° the light distribution due to diffraction will be identical, and so the device effectively operates as a type A device only. It is possible to combine this with non-diffractive structures at ±45° to the above which will become visible when viewed with the aid of a polarizer. This can be used to reveal numbers, letters or symbols encoded on the DOVID.

Fourth embodiment

Referring to Figure 8, this embodiment comprises a structure with steps on which a diffractive aligning pattern (or a non diffractive aligning pattern in part) is superimposed. As previously, there is a substrate 80 on top of which is provided a coating of a liquid crystal material 82 of similar properties to that of the previously embodiments. As previously the device may be used in reflective or transmissive modes or a mixture of both, by selective application of a reflective layer 84. The substrate carries a pattern 86 which may provide alignment and diffraction properties or alignment alone.

In this embodiment, the substrate has discrete steps of d_1 to d_4 depth. The pitch S of these steps can be few millimetres e.g. S>>p. The stepped surfaces can each carry a micro-relief pattern or alignment structure 86. The diffraction due to this micro-relief pattern will be seen in normal visualisation (e.g. by the naked eye) and the steps will not be seen (because S>>p). For example, the micro-relief pattern can have a pitch of 1.0 μm and depth of 0.2 μm (or part of it can have micro-structures of the aligning-only regime).

The depths of the steps, d_1 to d_4, can be selected to give a particular retardation δ according to $\delta = 2d\,(n_e - n_o)$ (reflective) or $\delta = d\,(n_e - n_o)$ (transmissive).

The stepped structure allows the provision of different retardations δ on the same device. The stepped structure is used to add another feature to the operation of the device, without extra manufacturing steps or different materials. The stepped structure may be achieved in various ways; for example, a modified origination method may be used to form the steps (e.g. multi-exposure of photo-

resist, or exposure of a grey level mask to give different exposure level, hence different depths when developed).

It is known (as shown in "New coloured Optical Security Elements using LPP/LCP Technology" Proceedings of SPIE Vol. 4672 (2002) and references therein) that films with specific retardation can generate colour effects when viewed through suitable polarizers. Hence d_1 to d_4 can be selected to give different colours. For example retardation $\delta = 0.580$ µm will generate blue colour while $\delta = 0.320$ µm will produce yellow colour. These correspond to layer thickness $d = 3.742$ µm and 2.065 µm respectively in transmission. These colours are much more evident in a transmissive configuration.

As previously mentioned, the actual aligning structure can be such that it only produce alignment and no diffraction. Thus with the aid of suitable polarizers different colours can be generated on the same device side by side.

For example, d_1, d_2 and d_3 can be selected to correspond to δ_1, δ_2, δ_3 for specific colours (for example red, green and blue) when viewed with the aid of suitable polarizers.

In a variation, this substrate may be sloping rather than stepped, or otherwise contoured to provide a selected continuous variation in retardation.

In the various embodiments, a relief micro-structure is produced to give rise to diffraction and can be used to align optically anisotropic type materials. There are two main types of structures:

a) structures which cause diffraction and alignment simultaneously.
b) structures which give rise predominantly to alignment and little or no diffraction.

Using these principles, there is a wide range of device configurations, which fall into the following exemplary categories:.

a) devices where diffraction and alignment occur simultaneously from the same region. When viewed with the naked eye they show a diffraction effect, and when viewed through polarizers they show both diffraction effect and the effect of polarization modification due to the alignment and the selection of appropriate retardation.

b) Devices with regions as above and regions which show no diffraction but only have polarization modulation effect (on the same substrate using the same liquid crystal material thickness).

c) Devices which have a coarse step structure of different thicknesses of liquid crystal material to give rise to different retardation (on the same device). On this structure a fine structure can be superimposed which can be of diffractive nature or aligning only nature. A variation of this is to provide devices with a sloping interface (with both types of the structure).

d) Device which can have different combinations of the above.

Thus the embodiments of this invention provide a single device using the same structure to encode both diffractive (type A) and Optical phase (type B) features. The diffractive device already is in the form of a micro-relief structure. If this structure is coated with Liquid Crystal Polymers or polymerisable liquid crystalline material of an appropriate thickness, then it will also act as the aligning structure, hence the same device will display diffractive optical security

features (type A) as well as optical phase features (type B).

The same origination and manufacturing process is used for both. The device will operate both as type A and type B – but from a single device and a single structure. These devices can be mass produced using origination and manufacturing techniques as type A which is cheaper and simpler than type B.

It should be noted that in all the above embodiments the refractive index of the first layer can be substantially matched with the ordinary or extraordinary refractive index of the optically anisotropic second layer. This will allow the creation of a device, or region within a device, where diffraction will occur only in one polarization.

Claims

1. An optical device comprising a first layer having a micro-relief pattern over at least part of said first layer designed to produce a predetermined diffracted first image when appropriately illuminated in use, and an optically anisotropic second layer provided on said first layer wherein at least part of said micro-relief pattern induces local orientation of said optically anistropic second layer thereby to impose a predetermined polarization modulation, thereby to produce a predetermined second image when appropriately illuminated and viewed in use.

2. An optical device according to Claim 1, wherein said first layer includes one or more relatively strongly diffractive regions having a significant diffractive effect and one or more relatively weakly diffractive regions where there is little or no diffractive effect.

3. An optical device as claimed in Claim 1 or Claim 2, wherein said first layer includes a plurality of areas, each of which having a respective orientation of the micro-relief pattern thereon, defining respective optical axes of the optically anisotropic second layer.

4. An optical device according to any of the preceding claims, wherein the coating thickness of the optically anisotropic second layer is selected having regard to the frequency, and the intended illumination in use, to provide a ½ λ phase retardation when appropriately viewed.

5. An optical device according to any of claims 1 to 3, wherein the coating thickness of the anisotropic optically alignable material is selected having regard to the frequency, the intended illumination in use, to provide a ¼ λ

phase retardation when appropriately viewed.

6. An optical device according to any of the preceding claims, wherein the average thickness of the optically anisotropic layer or its birefringence varies with position across said device to vary the optical retardation induced thereby.

7. An optical device according to any of the preceding claims wherein the first layer is provided on a stepped substrate, whereby adjacent micro-relief patterns are stepped in the vertical sense by a step distance which is substantially greater than the structure pitch dimension, thereby to provide regions of respective selected retardations.

8. An optical device according to Claim 6, wherein said first layer is provided on a generally continuously contoured substrate.

9. An optical device according to Claim 8, wherein said first layer is sloping to provide a linear variation in coating depth.

10. An optical device according to any of the preceding claims, wherein the interface between the first layer and the optically anisotropic second layer is reflective over at least part of the device whereby at least part of said device is adapted to operate in reflection mode.

11. An optical device according to any of the preceding claims, wherein the first layer comprises a transmissive substrate and at least part of the surface thereof remote from the interface with the optically anisotropic layer is reflective.

12. An optical device according to any of the preceding claims, adapted in use to operate in transmission mode.

13. An optical device according to any of the preceding claims, adapted in use to operate in reflection mode.

14. An optical device according to any of the preceding claims, wherein said second layer comprises a polymerisable liquid crystalline material.

15. An optical device according to any of the preceding claims, wherein said second layer is a polymer liquid crystal material.

16. An optical device according to any of the preceding claims, wherein said second layer is fixed into a solid film thus preserving its orientation.

17. An optical device according to any of the preceding claims, wherein the refractive index of first layer is substantially equal to the ordinary or extraordinary refractive index of the optically anisotropic second layer.

18. A method of producing an optical device which comprises providing a first layer having a micro-relief pattern over at least part of said first layer designed to provide a predetermined diffracted first image when appropriately illuminated in use, and applying to said first layer a coating of optically anisotropic second layer wherein at least part of said micro-relief pattern induces local orientation of said optically anisotropic second layer thereby to impose a predetermined polarization modulation thereby to produce a predetermined second image when appropriately illuminated in use.

19. A method according to Claim 18, wherein said micro-relief pattern is formed by embossing a suitable substrate.

20. A method according to Claim 18, wherein said micro-relief pattern is formed by UV curing of a suitable material in contact with a master with a micro-relief pattern.

21. An article including an optical device according to any of Claims 1 to 17.

Reflective mode

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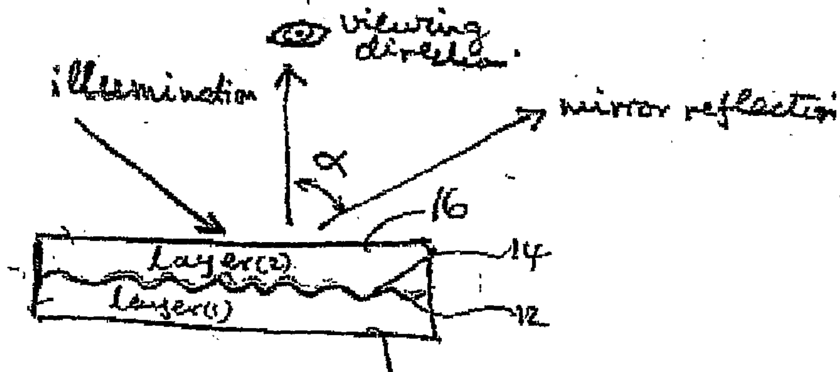

Figure 1

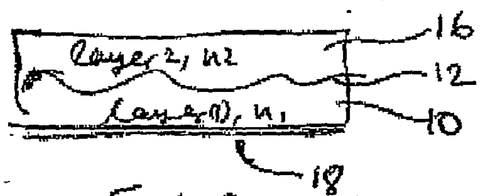

Figure 2

Transmissive mode

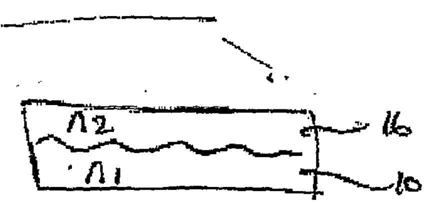

Figure 3.

reflective mode

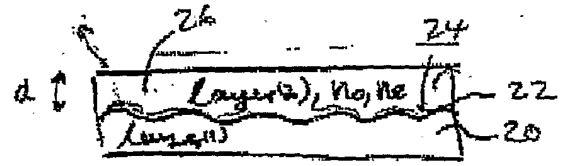

Figure 4

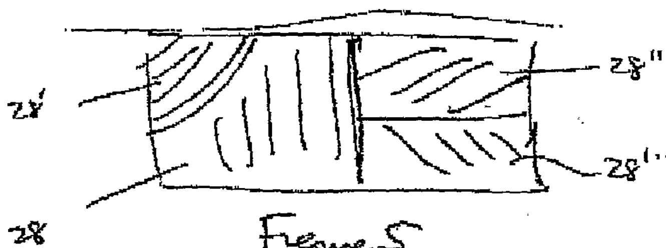

Figure 5

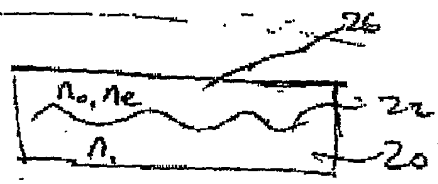

Figure 6

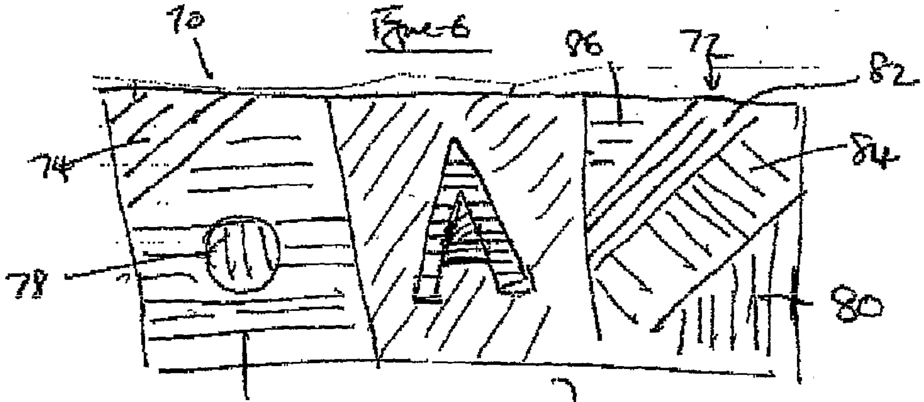

Figure 7

3/3

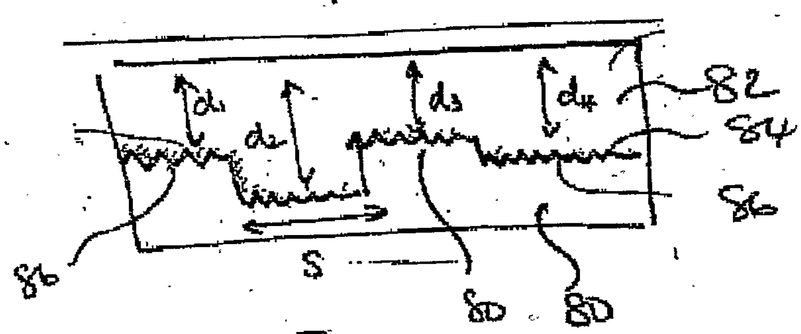

Figure 8